How Much of South Korea's Growth Miracle Can be Explained by Trade Policy?

Michelle Connolly
Duke University

Kei-Mu Yi
Federal Reserve Bank of Minneapolis[1]

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[1] Previous version: July 2014. First version: July 2012. Connolly: Department of Economics, Duke University, Durham, NC, 27708; connolly@econ.duke.edu; Yi: Research Department, Federal Reserve Bank of Minneapolis, 90 Hennepin Avenue, Minneapolis, MN, 55401; Kei-Mu.Yi@mpls.frb.org. We thank the editor and three anonymous referees for extremely valuable comments and suggestions. We also thank our discussants Sam Kortum, Richard Rogerson, Kathryn Russ, and Jian Wang for very helpful comments. We benefited from conversations with James Anderson, Susanto Basu, John Fernald, Jeremy Greenwood, Virgiliu Midrigan, and Andrea Raffo. We thank participants at the SED Meetings, AEA Meetings, New York Fed, Penn State, IMF, Philadelphia Fed, the San Francisco Fed Pacific-Basin Conference, ITAM, Drexel, the NBER EF&G Growth Summer Institute, U.S. ITC, the UCSB LAEF Conference, Virginia, Yale, Boston College, the Yonsei Macro Theory and Policy Conference, Bank of Italy, U. of Manitoba, Princeton, Federal Reserve Board, Houston, Toronto, Bank of Korea, and Bank of Canada for useful suggestions. Jingyi Jiang, Edith Ostapik and Mohan Anand provided excellent research assistance. The views expressed in this paper are those of the authors and are not necessarily reflective of views of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

Abstract

South Korea's growth miracle has been well documented. A large set of institutional and policy reforms in the early 1960s is thought to have contributed to the country's extraordinary performance. In this paper, we assess the importance of one key set of policies, the trade policy reforms in Korea, as well as the concurrent GATT tariff reductions. We develop a model of neoclassical growth and trade that highlights two forces by which lower trade barriers can lead to increased per worker GDP: comparative advantage and specialization, and capital accumulation. We calibrate the model and simulate the effects of three sets of tariff reductions that occurred between early 1962 and 1995. There are two main findings. First, the model can explain about 17 percent of South Korea's catch-up to the G7 countries in value-added per worker in the manufacturing sector. Second, these gains, as well as most of the welfare gains, are attributed to two key transmission channels: multi-stage production and imported investment goods.

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1 Introduction

Well before India and China burst onto the global scene, there were the growth miracles of the Newly Industrializing Countries. South Korea was one of those countries and its experience since the early 1960s has been widely documented.[1] In 1961, according to the Penn World Tables, South Korea's per capita GDP was 11% of that of the United States, about the same as in the Ivory Coast and Sri Lanka at that time. By 1995 its per capita GDP was 49% of the United States, comparable to Portugal or Slovenia. In the intervening period, South Korea (hereafter, "Korea") experienced growth rates of real per capita GDP that averaged 6.6 percent per year. A key feature of this miracle was an enormous increase in Korea's international trade. Korea's merchandise export share of GDP rose from just 2 percent in 1962 to 30 percent in less than 20 years. Virtually all of this increase was in manufactured goods. In 1960, only 35.2 percent of Korea's merchandise exports consisted of manufactured goods. In 1995, it was 96.9 percent.[2]

The growth miracle came on the heels of a sweeping set of policy reforms following the ascension of Park Chung Hee to power in 1961. One major area of reforms was in trade policy. Park believed that Korea needed to start exporting, but recognized that the country had few natural resources. Consequently, trade policy shifted from largely focusing on import substitution to one focused on export expansion. Hong (1979) documents 38 reforms designed to promote exports. Of these reforms, two stand out. In the early 1960s, Korea eliminated tariffs on imported inputs and capital goods, but only as long as these imports were used to produce goods for export. The imports could not be used for production of goods sold domestically. Westphal and Kim (1977) show that, at least until 1975, this was the most important export-oriented policy in Korea. Second, beginning in the 1970s and continuing for the next two decades, Korea engaged in a broader, gradual reduction of general tariff rates from about 40 percent to 13 percent. During this period, there were significant changes occurring in the global trading environment, as well. Perhaps GATT's two most important set of global tariff reductions occurred between 1968 and 1986 with the implementation of the Kennedy Round and the Tokyo Round agreements.

The purpose of this paper is to assess the importance of these trade reforms in explaining Korea's growth in GDP per worker and trade between 1962 and 1995, the growth miracle period. We conduct our quantitative assessment through the lens of an open economy general equilibrium

[1] See, for example, Lucas (1993). The other Newly Industrializing Countries are Hong Kong, Taiwan, and Singapore.

[2] If the food, beverages and tobacco sector is counted as manufacturing, the manufacturing share of total merchandise imports was 46.6 percent in 1960 and 98.9 percent in 1995.

framework that marries the neoclassical models of growth and trade. The growth theory underlying our model is Cass-Koopmans. The trade theory underlying the model is Ricardian; relative productivity differences across countries help determine differences in comparative advantage. Two additional features of the model are that some goods are produced in multiple stages and investment goods are tradable. These features allow the calibrated model to capture important facts in Korea's growth experience.

The growth theory and the trade theory in our model are linked in the following ways. Lower tariffs raise allocative efficiency because this facilitates specialization. The presence of multiple stages of production deepens the extent of specialization. Countries specialize by stages, as well as by goods. The efficiency gains show up as increases in aggregate total factor productivity (TFP) even though there are no intrinsic increases in the productivity of any individual good. The lower tariffs also generate increased imports of investment goods, and greater capital accumulation more broadly. Thus, the trade liberalization induces higher aggregate TFP and capital accumulation, both of which facilitate increases in GDP per worker.

We calibrate the model to match key features of the manufacturing sector in Korea vis-a-vis the G7 countries in 1962 and 1963. We then simulate the three sets of tariff reductions highlighted above. Our main findings are as follows. Taken together, the tariff reductions can explain 17 percent of Korea's catch-up in manufacturing value-added per worker. Owing to real exchange rate effects, the individual tariff reductions may not raise Korea's GDP measured in units of the G7 goods, but each policy does raise welfare. We also use our model to study the importance of multi-stage production and imported investment; we show that these transmission channels explains the vast majority of the model's implications for the catch-up and the growth in trade.

The role of trade policy in affecting trade, productivity, and long run growth is a story involving international economics, development economics, and macroeconomics. Economists from each of these sub-disciplines have typically approached this question with varying empirical methodologies including reduced form regressions, structural regressions, micro and macro growth regressions, and event studies. What most of these approaches have in common is a focus on differences across countries, industries, or firms. Often, the identification assumptions necessary to provide valid econometric estimates preclude drawing inferences about the effect of changes in tariffs on outcomes in levels, such as GDP per capita. Also, Rodriguez and Rodrik (RR, 2001) demonstrate that some of the leading empirical research that finds a significant effect of trade policy on growth has either flaws in the methodology or results that are not robust.[3] Two of RR's prescriptions for research are to study contingent relationships and to study the "channels through which trade policies influence economic performance."[4] Our methodology — because we are applying an open economy structural model to study an actual growth experience — is consistent with these prescriptions. More broadly, very few models have been applied to study actual growth experiences, including the growth miracles. Little attention has been devoted to assessing the ability of trade or growth models, let alone models of trade and growth, to account for time series changes that occur in particular episodes such as the Korean growth miracle. The latter is what we do.[5]

The next section overviews key facts about the manufacturing sector, the focus of our calibration. Section 3 presents the model and discusses the core intuition of the effects of trade barrier reductions. Section 4 provides the calibration of the model. This is followed by the simulation of the trade liberalizations and the main results. Section 6 discusses further results, and the final section concludes.

2 Overview of Manufacturing Value-Added and Trade

This section provides key manufacturing facts about South Korea, as well as for the G7 countries. (Unless indicated, all variables refer to the manufacturing sector). These facts underlie the model that we develop, the model's calibration, and our assessment of the validity of the model.

Table 1 shows that Korea's manufacturing value-added per worker grew by close to an order of magnitude between 1963 and 1995. During this period, the capital/output ratio in manufacturing grew by considerably less, only about 50%. We use the Hall and Jones (1999) or Klenow and Rodriguez-Clare (1997) methodology in which capital accumulation induced by higher TFP is attributed to TFP. We find that TFP accounts for about 87% of Korea's growth in manufactured value-added per worker.[6] In addition, Table 1 shows that Korea's manufacturing value-added per

[3] Wacziarg and Welch (2008) address most of Rodriguez and Rodrik's critique of Sachs and Warner (1995). However, some of the broader concerns in the critique remain.

[4] Rodriguez and Rodrik, p. 266.

[5] There have been a few closed economy models that have been calibrated to study Korea's experience; see, for example, Chang and Hornstein (2011) and Papageorgiu and Perez-Sebastian (2006).

Recently, there has been research studying Korea's structural change. See, for example, Sposi (2012), Teignier (2012), Uy, Yi, and Zhang (2013), and Betts, Giri, and Verma (2014).

[6] Young (1995) performs a growth accounting decomposition of Korea's manufacturing sector. Using Young's data from his Table VII, but applying the method employed by Klenow and Rodríguez-Clare (1997), as well as by Hall and Jones (1999), we find that TFP growth accounts for 73.8 percent of Korea's growth in manufacturing GDP per worker between 1966 and 1990.

Using unpublished data from the BLS, (we thank Steve Rosenthal for providing this data), and the Divisia index approach of Basu and Fernald (1997), we compute the contribution of manufacturing TFP growth in the U.S.'s worker relative to the G7 countries more than doubled from 0.17 to 0.4.

Table 1: South Korea Manufacturing Growth Accounting and GDP relative to G7

Variable	1963	1995	(log) Growth	Contribution to growth of VA/L
Y/L (mill of 2005 won)	2.47	21.43	2.16	
K/Y	1.40	2.14	0.43	13.2%
TFP			1.88	86.8%
Y/L (relative to G7; current U.S.$)	0.17	0.40		

Notes: Y: value-added; L: labor; K: capital. All variables refer to manufacturing sector;

See Appendix A.2 for data sources and accounting methodology

The top row of Table 2 shows the well known fact of the enormous increase in Korea's exports. Expressed as a share of manufacturing value-added, exports rose by a factor of six between 1963 and 1995. The growth of manufactured trade had two important features associated with it. First, a large fraction of the growth in trade consisted of increased imports of capital goods. Imported equipment and machinery, expressed as a fraction of total manufacturing value-added rose from 19% to 38% between 1963 and 1995. Second, the importance of imported inputs used to make exported goods increased over time. In the language of Hummels, Ishii, and Yi (2001), there was an increasing amount of vertical specialization. Table 2 below shows that the value of manufactured imported inputs embodied in manufactured exports, expressed as a share of manufactured value-added, rose from 4.9% to 28.9% between 1963 and 1995.

Table 2: South Korea Manufacturing Trade (share of manuf GDP)

Variable	1963	1995
Exports	0.15	0.92
Imported equipment and machinery	0.19	0.38
Vertical specialization	0.049	0.29

Sources: See Appendix A.2.

3 The Model

In this section, we describe the model. The model combines neoclassical trade with neoclassical growth. In a neoclassical trade framework, comparative advantage and the costs of international

growth in manufacturing value-added per hour worked between 1966 and 1990. TFP accounted for 74.1 percent of the growth.

trade determine the pattern of production, specialization, and trade. We employ a Ricardian setting that draws from Eaton and Kortum (2001, 2002), as well as Yi (2003, 2010).[7] In the neoclassical growth framework, aggregate TFP and the capital stock determine per capita output. The link between these two frameworks is that trade barrier reductions – by facilitating the reallocation of resources to more efficient uses – will increase aggregate TFP and the capital stock. Trade will increase of course, as well. Two channels that can potentially accentuate the effect of trade barrier reductions are trade in investment goods, and production that occurs in multiple, sequential stages. Below, we first lay out the benchmark model, then we discuss the key transmission channels. We also show how the model is modified to allow for Korea's tariff exemption policy.

3.1 Technologies

There are two countries, H and F. There are two sectors, an investment goods sector and a consumption-cum-intermediate goods sector. (Hereafter, we will refer to the second sector as the consumption sector.) Each sector consists of a continuum of goods. An investment good $z \in [0,1]$ is produced from capital, labor, and the aggregate intermediate good. These investment goods are costlessly combined to yield an aggregate, non-traded, investment good that adds to the economy's capital stock. A consumption good $z \in [0,1]$ is produced in two sequential stages, i.e., there is multi-stage production of consumption goods.[8] First, capital, labor and the aggregate intermediate are combined to make a "stage 1" good. Then, the stage 1 good is combined with capital and labor to make the "stage 2" good. These stage 2 goods are costlessly combined to yield an aggregate, non-traded good used for consumption and as an intermediate in production. All stages of the continuum of investment and consumption goods are tradable. Only the aggregate goods are non-tradeable.

The production function for stage 1 consumption goods is given by:

$$y_{i1}(z) = (A_{i1}(z)k_{i1}(z)^{\alpha}l_{i1}(z)^{1-\alpha})^{1-\theta_1}M_i(z)^{\theta_1} \qquad z \in [0,1] \tag{1}$$

where $A_{i1}(z)$ is country i's total factor productivity associated with stage 1 good z, and $k_{i1}(z)$, $l_{i1}(z)$, and $M_i(z)$ are country i's inputs of capital, labor and aggregate intermediate M_i used to

[7] See also Alvarez and Lucas (2007), Waugh (2010), and Caliendo and Parro (2014). For a Heckscher-Ohlin model of trade and growth, see Ventura (1997), Bajona and Kehoe (2010), and Caliendo (2011).

[8] Eaton and Kortum (2001) show that capital goods production is dominated by a few advanced countries. Consequently, we assume these goods are produced in a single stage.

produce $y_{i1}(z)$. The share of intermediates in production is θ_1.[9] This first stage is a Cobb-Douglas version of the production function in Eaton and Kortum (2002) with value-added augmented to include capital.

The production function for stage 2 consumption goods is given by:

$$y_{i2}(z) = (A_{i2}(z)k_{i2}(z)^{\alpha}l_{i2}(z)^{1-\alpha})^{1-\theta_2}x_{i1}(z)^{\theta_2} \qquad z \in [0,1] \tag{2}$$

where $x_{i1}(z)$ is country i's use of $y_1(z)$ for stage 2 production, $A_{i2}(z)$ is country i's total factor productivity associated with stage 2 good z, and $k_{i2}(z)$ and $l_{i2}(z)$ are country i's labor used in producing $y_{i2}(z)$. Under autarky, $x_{i1}(z) = y_{i1}(z)$. The share of intermediates for this stage is θ_2.

The stage 2 consumption goods are costlessly assembled to produce an aggregate non-traded good X_i, which is used for consumption, C_i, and as an intermediate in production, M_i:

$$X_i = \exp\left[\int_0^1 \ln(x_{i2}(z))dz\right] = C_i + M_i \tag{3}$$

where $x_{i2}(z)$ is the amount of the stage 2 good z used to produce X_i.

Investment goods are also produced from capital, labor and the aggregate intermediate:

$$y_{iI}(z) = (A_{iI}(z)k_{iI}^{\alpha}(z)l_{iI}(z)^{1-\alpha})^{1-\theta_1}M_{iI}(z)^{\theta_1} \qquad z \in [0,1] \tag{4}$$

where $A_{iI}(z)$ is country i's total factor productivity (TFP) associated with the investment good z, and $k_{iI}(z)$, $l_{iI}(z)$, and $M_{iI}(z)$ are country i's inputs of capital, labor and aggregate intermediate M_i used to produce $y_{iI}(z)$. These investment goods are costlessly assembled into an aggregate non-traded investment good, I_i:

$$I_i = \exp\left[\int_0^1 \ln(I_i(z))dz\right] \tag{5}$$

where $I_i(z)$ is country i's use of $y_{iI}(z)$ for production of I_i.

Note that the capital share of value-added is the same across all production functions and countries. This is a requirement for comparative advantage to be based solely on Ricardian motives. In a Ricardian trade model, comparative advantage is based on relative productivity differences across countries. That is, the TFP terms $A_{i1}(z), A_{i2}(z)$, and $A_{iI}(z)$ determine comparative advantage.

[9] Including intermediates in the first stage of production facilitates matching gross output, trade, and value-added in the calibration.

Following Eaton and Kortum (2002), hereafter, EK, we model the TFPs as being drawn from a Frechét probability distribution:

$$F(A_{ix}) = e^{-T_{ix}A_{ix}^{-n}} \quad i = H, F \tag{6}$$

The mean of A_{ix} is increasing in T_{ix}. n is a smoothness parameter that governs the heterogeneity of the draws from the productivity distribution. The larger n is, the lower the heterogeneity or variance of A.

3.2 Trade Costs

There are two types of trade costs, both expressed in ad valorem terms. When the stage 1 or stage 2 consumption goods, or the investment goods, are shipped from country i to country j, they incur a tariff, $b_{ij,x}$, where x is the type of good, e.g., stage 1 consumption good. The second type of trade cost is a stand-in for all other trade costs, $tr_{ij,x}$, which includes, for example, transport costs. Total trade costs, then, are given by $1 + \tau_{ij,x} = (1 + b_{ij,x})(1 + tr_{ij,x})$. Revenue from the tariffs is rebated to households as lump-sum transfers. $tr_{ij,x}$ is modeled as an iceberg cost. So, if one unit of a type x good is shipped from i to j, $1/(1 + tr_{ij,x})$ units arrive in j.

3.3 Prices

We assume perfect competition in all stages, including the aggregator stages, of both types of goods. The price that a stage 2 consumption good firm in country j pays to purchase stage 1 of consumption good z from a country i firm is given by:

$$p_{ij1}(z) = \frac{\psi_1(1 + \tau_{ij1})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_1} P_i^{\theta_1}}{A_{i1}(z)^{1-\theta_1}} \tag{7}$$

where $\psi_1 = (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)})^{1-\theta_1}\theta_1^{-\theta_1}(1-\theta_1)^{-(1-\theta_1)}$, and w_i, R_i, P_i, and $A_{i1}(z)$ are country i's wage rate, rental rate on capital, price of the aggregate intermediate good, and stage 1 consumption good productivity for good z. The actual price that the stage 2 consumption good firm in country j will pay is $p_{j1}(z) = \min\left[p_{ij1}(z); i = H, F\right]$.

The price that the consumption aggregator firm in country j pays to purchase stage 2 of consumption good z from a country i firm is given by:

$$p_{ij2}(z) = \frac{\psi_2(1+\tau_{ij2})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_2} p_{i1}(z)^{\theta_2}}{A_{i2}(z)^{1-\theta_2}} \tag{8}$$

where $\psi_2 = (\alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)})^{1-\theta_2}\theta_2^{-\theta_2}(1-\theta_2)^{-(1-\theta_2)}$. The actual price that the consumption aggregator firm in country j pays is $p_{j2}(z) = \min\left[p_{ij2}(z); i = H, F\right]$. From (7) and (8), it can be seen that $p_{j2}(z)$ potentially embodies two sets of trade costs — one in importing the stage 2 good, and one in importing the stage 1 good to make the stage 2 good. This multiplicative possibility is one of the forces underlying the magnification effect with multi-stage production and vertical specialization.

The price that an investment aggregator firm in country j pays to purchase the investment good z from a country i firm is given by:

$$p_{ijI}(z) = \frac{\psi_1(1+\tau_{ijI})(R_i^{\alpha} w_i^{1-\alpha})^{1-\theta_1} P_i^{\theta_1}}{A_{iI}(z)^{1-\theta_1}} \tag{9}$$

The actual price that the investment aggregator firm in country j pays is $p_{jI}(z) = \min\left[p_{ijI}(z); i = H, F\right]$.

3.4 Households

The representative household in country i maximizes:

$$\sum_{t=0}^{\infty} \beta^t \frac{C_{it}^{1-\sigma} - 1}{1-\sigma} \tag{10}$$

subject to a sequence of budget constraints:

$$P_{it}C_{it} + P_{Iit}I_{it} = w_{it}L_{it} + r_{it}K_{it} + T_{it} \tag{11}$$

where C_{it} is consumption of the aggregate non-traded good, and T_{it} is the lump sum rebate of tariff revenue, in period t. P_{it} and P_{Iit} are the prices of the aggregate consumption and investment good, respectively. The numeraire is the foreign consumption good. The elasticity of intertemporal substitution is $\frac{1}{\sigma}$. Households own the capital and rent it period-by-period to the consumption and investment goods firms.[10] Capital is accumulated in the standard way:

$$K_{it+1} = (1-\delta)K_{it} + I_{it} \tag{12}$$

3.5 Equilibrium conditions

All factor and goods markets are characterized by perfect competition. The following factor market clearing conditions hold for each country in each period:

$$L_i = \int_0^1 l_{i1}(z)dz + \int_0^1 l_{i2}(z)dz \ + \int_0^1 l_{iI}(z)dz \tag{13}$$

$$K_i = \int_0^1 k_{i1}(z)dz + \int_0^1 k_{i2}(z)dz \ + \int_0^1 k_{iI}(z)dz \tag{14}$$

The stage 1 consumption goods market equilibrium condition for each z is:

$$y_1(z) \equiv \sum_{i=1}^{2} y_{i1}(z) = \sum_{i=1}^{2}(1 + tr_{ki1}(z))x_{i1}(z) \tag{15}$$

where $(1+tr_{i1}(z))$ is the all other trade costs incurred by shipping the stage 1 good from country i's cheapest source k to country i. The condition states that total production of the stage 1 good equals the total demand, inclusive of trade costs, for that good. A similar set of conditions applies to each stage 2 consumption good z and each investment good z:

$$y_2(z) \equiv \sum_{i=1}^{2} y_{i2}(z) = \sum_{i=1}^{2}(1 + tr_{ki2}(z))x_{i2}(z) \tag{16}$$

$$y_I(z) \equiv \sum_{i=1}^{2} y_{iI}(z) = \sum_{i=1}^{2}(1 + tr_{kiI}(z))I_i(z) \tag{17}$$

Finally, the aggregate consumption and intermediate good must be completely absorbed in each country i:

$$X_i = C_i + M_i = C_i + \int_0^1 M_i(z)dz + \ + \int_0^1 M_{iI}(z)dz \tag{18}$$

[10] Note that we do not allow the countries to run current account deficits. S. Korea ran current account deficits during the 1960s and 1970s, and then balanced trade or surpluses beginning in the mid-1980s. Allowing for current account deficits would be a useful extension.

If these conditions hold, then each country's exports equals its imports, i.e., balanced trade holds. We now define the equilibrium of this model:

Definition 1 *An equilibrium is a sequence of goods prices,* $\{p_{i1}(z), p_{i2}(z), p_{iI}(z), P_i, P_{Ii}\}$*; factor prices,* $\{w_i, r_i\}$*; factor inputs,* $\{l_{i1}(z), l_{i2}(z), l_{iI}(z), k_{i1}(z), k_{i2}(z), k_{iI}(z)\}$*; intermediate inputs,* $\{M_i(z), M_{iI}(z)\}$*; and outputs,* $\{y_{i1}(z), y_{i2}(z), y_{iI}(z), x_{i1}(z), x_{i2}(z), I_i(z), C_i, I_i, M_i\}$, $z \in [0,1]$, $i = H, F$*, such that the first order conditions to the households' maximization problem 10, the first order conditions to the firms' maximization problems associated with production functions 1-5, as well as the market clearing conditions 13-18 are satisfied.*

3.6 Implementing Korea's Tariff Exemption on Imported Inputs and Investment Goods

The model presented above characterizes the initial steady-state, prior to the implementation of the trade policy reforms. As discussed above, one of Korea's major trade policy reforms was the tariff exemption policy on imported inputs and capital goods. That is, with this reform, the price that Korean firms paid for these imports depended on their ultimate destination. Implementing the tariff exemption on imported inputs is straightforward. In the language of our model, with this policy, stage 2 goods z that are produced in the following way: country F makes stage 1, and country H (Korea) makes stage 2, i.e., production method FH, and that are subsequently exported to country F, become cheaper to produce. They are cheaper via two channels. First, Korea's import tariff no longer applies to the stage 1 goods z imported from F by Korea. Second, the capital used to produce stage 2 will consist of investment goods z, some of which were imported without tariffs, as well. Consequently, from the perspective of the foreign consumption aggregator firm, stage 2 goods produced via method FH are now cheaper, and more of these goods will be purchased.

Implementing the tariff exemption on these particular imported investment goods is more complicated because these investment goods can only be a part of a capital stock that is used to produce goods via HH, HF, and FH (and that are exported). To encompass this, we introduce to our model a second capital stock in country H (Korea), K_H^E, which is used only to produce goods via HH, HF,and FH that are subsequently exported. This capital stock is initially zero, and is accumulated via a second aggregate investment good, I_H^E, once the exemption is implemented. The second aggregate investment good is a composite of domestic investment goods z and of investment goods z that are imported duty-free. The first capital stock is the same as before, except it is not used to produce the HH, HF, FH-and-subsequently-exported goods.

The budget constraint for the household in country H is now:

$$P_{Ht}C_{Ht} + P_{HIt}I_{Ht} + P_{HIt}^{E}I_{Ht}^{E} = w_{Ht}L_{Ht} + r_{Ht}K_{Ht} + r_{Ht}^{E}K_{Ht}^{E} + T_{Ht} \tag{19}$$

where P_{HIt}^{E} and r_{Ht}^{E} are the price of the aggregate investment good and the rental rate on the aggregate capital stock, respectively, that are used to make export goods via FH.

3.7 Trade, Vertical Specialization, and Growth and Income

We now discuss the model's implications for trade and for steady-state per capita income. We highlight the transmission channels from reductions in trade costs to higher trade and per capita income.

3.7.1 Trade and Vertical Specialization

Under autarky, each country produces the entire range of stage 1 consumption goods, stage 2 consumption goods, and investment goods. There is no specialization. At the other extreme is frictionless trade – tariffs and all other trade costs are zero – which yields complete specialization. Each stage of each good will be produced by only one country.

Starting from autarky, if trade barriers fall, specialization and trade will emerge as countries find it cheaper to import some stages of some goods. Which country produces which stage of which good depends on the interplay of relative productivity differences across countries, relative factor costs, and trade costs. For example, consider the country H investment aggregator firm. This firm can purchase the investment goods z from country H or country F. A particular good z will be purchased from country H if the following condition holds:

$$p_{HI}(z) \equiv \frac{\psi_1 (w_H^{1-\alpha} r_H^{\alpha})^{1-\theta_1} (P_H)^{\theta_1}}{A_{HI}(z)^{1-\theta_1}} < \frac{(1+\tau_{FH,I})\psi_1 (w_F^{1-\alpha} r_F^{\alpha})^{1-\theta_1} (P_F)^{\theta_1}}{A_{FI}(z)^{1-\theta_1}} \equiv (1+\tau_{FH,I}) p_{FI}(z) \tag{20}$$

The above equation essentially says that if H's production costs relative to its TFP is less than F's production costs (inclusive of trade costs) relative to its TFP, the good will be purchased from H. More generally, the home country price of an investment good z, $p_I^H(z) = \min\left[p_{HI}(z), (1+\tau_{FH,I})p_{FI}(z)\right]$.

To produce a stage 2 consumption good z, there are four possible methods: $HH, FH, HF,$ and

FF, where FH means the first stage is produced in country F and the second stage is produced in country H. If the second stage is produced in H, then $p_{H2}(z) = \min[p_{HH}(z), p_{FH}(z)]$. Similarly, if the stage 2 good is produced in F, then $p_{F2}(z) = \min[p_{HF}(z), p_{FF}(z)]$. Then, the world price of the good, $p_2(z) = \min[p_{H2}(z), p_{F2}(z)] = \min[p_{HH}(z), p_{FH}(z), p_{HF}(z), p_{FF}(z)]$.

If one country is relatively more productive at making investment goods than consumption goods, it will tend to specialize in investment goods, and run a trade surplus in those goods and a trade deficit in consumption goods. However, owing to our distributional assumptions about the productivities, the country will also import some investment goods, and produce and export some consumption goods. In this sense, there is intra-industry trade.[11]

In general equilibrium, wages, rental rates, and intermediate goods prices are determined so that each country's production equals its spending and each country's exports equals its imports. Each country will find some goods for which the other country is the low cost producer. This is the essence of comparative advantage and general equilibrium.

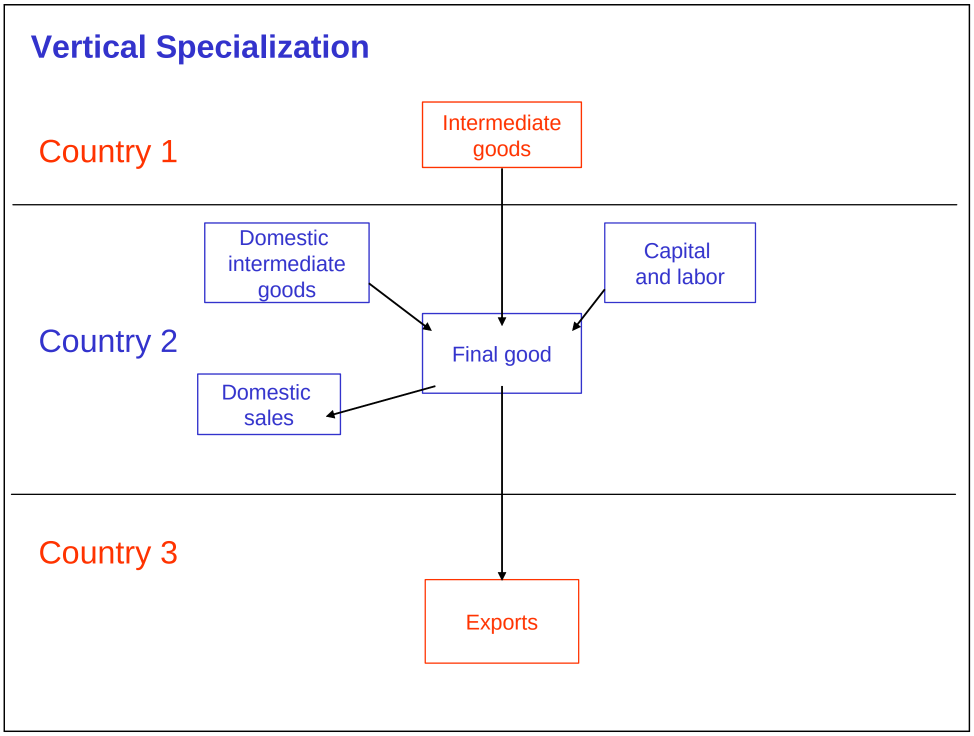
The presence of multi-stage production for consumption goods leads to the possibility of vertical specialization. Drawing from Hummels, Ishii, and Yi (HIY, 2001) and Yi (2010), we define *vertical* specialization to occur when one country uses inputs imported from another country in its stage of the production process, and some of the resulting output is exported to another country.[12] Figure 3 illustrates an example of vertical specialization involving three countries. The key country is country 2. It combines the imported intermediates with other inputs and value-added to produce a final good or another intermediate good in the production chain. Then, it exports some of its output to country 3. If either the imported intermediates or exports are absent, there is no vertical specialization. By this definition, consumption goods produced by production method FH and exported back to country F or goods produced by production method HF and exported back to country H are vertically specialized. A necessary condition for vertically specialized production of a good to occur is for one country to be relatively more productive in the first stage of production and another country to be relatively more productive in the second stage.

HIY's primary measure of vertical specialization is essentially the imported intermediates content of exports. HIY use data from input-output tables to compute industry-level and national

[11] See Davis (1995), which is, to our knowledge, the first model of intra-industry trade in a perfect competition, comparative advantage setting.

[12] Also, see Hummels, Rapoport, and Yi (1998), and Yi (2003). Johnson and Noguera (2012, 2014) and Koopman, Wang, and Wei (2014), among others, have generalized and extended the methodology of HIY (2001). In our calibration, vertical specialization is computed from the model in the same way HIY compute it in the data.

Figure 1: Vertical Specialization



measures of vertical specialization for several countries over time.[13] Table 2 above showed that growth in vertical specialization has been a large part of Korea's trade experience.

Yi (2003) demonstrates that with multi-stage production and vertical specialization, the effects of trade barrier reductions on trade are magnified. Here, we provide a simple example drawing from Yi (2010) to illustrate this point and describe the intuition underlying it. Suppose that there are only consumption goods and they are produced only in a single stage. If both countries have the same labor endowment, both countries' productivities are drawn from the same Frechét distribution, and trade costs are symmetric between countries, then in equilibrium the import share of GDP is given by:

$$\frac{1}{1+(1+\tau)^n} \tag{22}$$

[13]Their primary measure is VS:

$$VS_{ki} = \left(\frac{Imported\ intermediates_{ki}}{Gross\ output_{ki}}\right) Exports_{ki} \tag{21}$$

where k and i denote country and good, respectively.

An additional advantage of using input-output tables is that they facilitate measuring the indirect import content of exports. Inputs may be imported, for example, and used to produce an intermediate good that is itself not exported, but rather, used as an input to produce a good that is. See Hummels, Ishii, and Yi (2001).

A key force determining the elasticity of trade with respect to trade costs is the parameter n from the Frechét distribution, which determines the variance or heterogeneity in productivities. If n is low, there is a great deal of heterogeneity, which makes it likely that one country is much more productive at making a good than the other country. Hence, specialization and trade patterns will not respond much to changes in trade costs. The opposite is true if n is high. Eaton and Kortum (2002) show that n plays the same role in their model as $\sigma - 1$, where σ is the elasticity of substitution between goods, in the monopolistic competition or Armington aggregator-based trade models.[14]

Now consider a case in which consumption goods are produced in two stages. There are still no investment goods, and the two countries continue to have the same labor endowments, the same underlying distribution of TFPs for each stage of production, and the same trade costs. This implies that wages, rents, and GDPs are equalized across countries. We also assume that the first stage of production is produced in the country that ultimately purchases the second stage good; only the second stage production location is determined by the model. Thus, if an H aggregator firm seeks to purchase an automobile, the parts and components are assumed to be produced in H, while final assembly can occur either in H or F. This assumption ensures that an analytical expression for the import share of GDP exists.

For goods consumed by the home country, the two possible production methods are HH and HF. Note that production method HF involves international vertical specialization: the foreign country imports inputs and exports its resulting output back to H. In Appendix A.1, we show that the import share of GDP can be expressed as:

$$\frac{\varphi}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{23}$$

Note that the responsiveness of the import share of GDP to trade costs depends on n, and also on the term $\left(\frac{1+\theta_2}{1-\theta_2}\right)$, which shows that multi-stage production magnifies the effects of trade costs. If $\theta_2 = 2/3$, for example, the exponent on the trade cost is five times larger than in a one-stage model. Two forces underlie the $\left(\frac{1+\theta_2}{1-\theta_2}\right)$ term. The first force is a "back-and-forth" force. With the HF production process, the first stage encounters trade costs twice; recall that the share of stage

[14] See Eaton and Kortum (2002, p. 1750, fn. 20) or Anderson and van Wincoop (2004, p. 710). Arkolakis, Costinot, and Rodríguez-Clare (2012) show that the Eaton and Kortum (2002), Armington aggregator, and Melitz (2003) frameworks all yield the same gains from trade. Our model does not fit into the class of models for which this is true.

1 goods in stage 2 production is θ_2. Consequently, the total effect of the trade cost owing to this force is $1+\theta_2$. The second force is an "effective rate of protection" force, because the concept is analogous to the concept from the literature of that name. The trade-off between HH and HF hinges on the second stage of production. The key idea is that the relevant or effective trade cost is the trade cost divided by the share of the second stage's value-added in the total cost. This is because the second stage is the marginal production stage, but the trade cost is applied to the entire good. If the second stage value-added accounts for one-third of the total cost, for example, then the effective trade cost is three times the nominal trade cost. This explains the $\frac{1}{1-\theta_2}$ term.[15] Note that the magnification of trade costs is independent of the intermediate input share θ_1. The presence of intermediates is necessary, but not sufficient, for a magnification effect.

3.7.2 Growth and GDP per capita

To explain how lower tariffs affects Korea's GDP per capita (hereafter, we use "GDP per capita" and "GDP per worker" interchangeably), we focus on the broad Korean tariff. We proceed in several steps by starting with a simple case of the model, and then adding layers.

We first consider a case without capital and investment goods. For this case, it will facilitate intuition to discuss welfare first, and then per capita GDP. Welfare in steady-state is just consumption per capita. As is well known, when tariffs on consumption goods decline, Korea's terms of trade will be adversely impacted, which lowers welfare. However, trade volumes increase owing to increased specialization, which increases welfare. For a small country like Korea, the specialization and trade volume effect will tend to dominate the terms of trade effect, especially when the declines in tariffs start from a high base. Overall, then, tariff declines are likely to be welfare improving. The effect on Korea's GDP per capita – in units of the foreign consumption good – is the effect on consumption multiplied by the effect on the real exchange rate – the price of Korean consumption goods in terms of the foreign consumption good. Lower Korean tariffs causes Korea's real exchange rate to depreciate as Korean consumption goods become cheaper.[16] While it may seem that the

[15] Another way to explain the $\left(\frac{1+\theta_2}{1-\theta_2}\right)$ term is via the following decomposition. In the HF production process, the first stage encounters trade costs when it is shipped to the foreign country. The trade costs are equivalent to a cost on the second stage of production of $(1+\tau)^{\frac{\theta_2}{1-\theta_2}}$. Trade costs are encountered again when the final good is shipped back to the home country from the foreign country. Now the trade cost is applied to the entire good. Consequently, a cost of $1+\tau$ is imposed on the entire HF-produced good, which is effectively a cost of $(1+\tau)^{\frac{1}{1-\theta_2}}$ on the second stage of production. The total effect is the product of these two forces. If trade costs fall, the cost of producing vertically specialized goods declines by a multiple of the fall. See Yi (2010).

[16] In a world with frictions to trade that lead to 'home bias' in goods and services, movements in the terms of trade tend to parallel movements in the real exchange rate. That is, forces that tend to worsen the terms of trade will also

effect is ambiguous because consumption rises, but the real exchange rate depreciates, the overall effect will be negative. This is because GDP per capita is essentially the wage rate. When tariffs decline, at the initial wage, there will be increased imports leading to a trade deficit. To restore equilibrium, the wage must decline.

Now add capital and investment goods. Assume a zero growth steady-state, and consider again a reduction in tariffs on consumption goods. As before, the terms of trade declines and the real exchange rate depreciates. The depreciation lowers Korea's GDP per capita (again in units of the foreign consumption good). Offsetting the real exchange rate effect is the increase in GDP owing to increased specialization and trade, and in addition, increased capital accumulation. The increase in specialization and allocative efficiency is effectively an increase in aggregate TFP, which then induces the capital accumulation. Note that aggregate TFP rises even though there has been no change in the efficiency of producing individual goods.[17] In the calibrated model, we will show that the overall effect on per capita GDP is still negative, i.e., the real exchange rate effect is dominant.

Now, consider a reduction in Korea's tariffs on investment goods. Again, there is an adverse impact on the terms of trade and the real exchange rate depreciates. As before, there is specialization-induced growth owing to increased aggregate TFP and capital accumulation. In addition, there is a direct capital accumulation effect, which can be illustrated via the steady-state household's Euler equation (for country H):

$$\frac{r_{H,ss}}{P_{HI,ss}} = \frac{1}{\beta} - (1 - \delta) \tag{24}$$

$P_{HI,ss}$ is the price of the home country aggregate investment good:

$$P_{HI,ss} = \exp\left(\int_{H^I} \ln(p_{HI}(z))dz + \int_{F^I} \ln((1 + \tau_{HI})p_{FI}(z))dz \right) \tag{25}$$

where H^I denotes the measure of goods z such that the lowest cost production source is in H;similarly, F^I denotes the measure of goods z such that the lowest cost production source is in F. The lower tariffs lower the price of the aggregate investment good through an intensive margin channel – the prices of imported investment goods declines – and through an extensive margin channel – there is a shift from relatively high cost domestic investment goods to relatively low cost

tend to lead to real exchange rate depreciation.

Note that if Korean GDP was evaluated at base year prices, rather than in units of the foreign consumption good, GDP per capita would rise.

[17] See Finicelli *et al* (2013) and Waugh (2010) for a derivation of how increased trade adds to aggregate TFP in an EK framework.

imported investment goods. The measure of H^I falls, while the measure of F^I rises. The lower price of the aggregate investment good induces capital accumulation, which continues until the return on capital $r_{H,ss}$ falls by enough so that the Euler equation holds again. The rise in capital and TFP increase per capita GDP, which, in addition to the forces described earlier, could further potentially offset the real exchange rate effect. Overall, the forces supporting an increase in per capita GDP are stronger than in the consumption tariff case.

How does multi-stage production work? Because multi-stage production provides greater avenues for specialization, it will induce greater effects on aggregate TFP, and, indirectly through TFP, capital accumulation. Hence, the effects on per capita GDP will be enhanced, although there is still no presumption that the effect is now large enough to overcome the real exchange rate depreciation and yield an overall increase in per capita GDP.

We briefly discuss the effects of the other two tariff policies. The reduction in G7 tariffs will lead to an improvement in Korea's terms of trade and an appreciation of Korea's real exchange rate, which, all else equal, will raise Korea's GDP in terms of the foreign consumption good, and it will shift the capital stock away from domestic production towards export production. The effects of the tariff exemption on Korea's imported inputs and capital goods are subtle; it has similarities to the reduction in Korean tariffs and the reduction in G7 tariffs. On the one hand, the exemption generates a worsening of the terms of trade — like the reduction in the Korean tariff. On the other hand, the price of the final consumption good, i.e., the real exchange rate, as well as the wage rate and the rental rate on domestic capital, increase, as happens with the reduction in G7 tariffs. What the tariff exemption and the G7 tariff reduction have in common is they lead to lower prices for the G7 household and firms. The differing real exchange rate effect between the Korean tariff exemption and the Korean tariff reduction is key to understanding how these two tariff policies are qualitatively different.

As mentioned earlier, Klenow and Rodríguez-Clare (1997) and Hall and Jones (1999) employ growth accounting decompositions in which capital accumulation that is induced by increased TFP is attributed to TFP. Their decomposition divides GDP per worker growth into TFP growth and growth in the capital-output ratio, K/Y. In our model with two sectors, tariff (and other trade cost) reductions will show up primarily as an increase in aggregate TFP and partly as an increase in the K/Y ratio. In addition, we can interpret reductions in investment goods tariffs as investment-specific technical change, and reductions in consumption goods trade costs as neutral technical change. Thus, our model implies that trade contributes to the two types of technical change highlighted in Greenwood, Hercowitz, and Krusell (1997).

4 Calibration to Korea and G7

We now calibrate the model presented in sections 2.1-2.5. The two countries H and F are Korea and the G7 countries. The latter were recipients of 74% of Korea's exports and shipped 86% of Korea's imports in 1962 (with even larger shares subsequently). We calibrate the model to the manufacturing sector of the two sets of countries. We choose this approach for three main reasons. First, there are more data available on manufacturing, and, because manufactured goods are traded more, it facilitates constructing measures of output that are comparable across countries. Second, Korea underwent an enormous structural transformation, which would necessitate modeling individual sectors and their interactions, if the calibration was to the entire economy. This is beyond the scope of this paper.[18] Third, manufacturing has had the highest productivity growth in Korea, and, as mentioned in the introduction, it was responsible for virtually all of the increase in trade.[19] Understanding the evolution of manufacturing value-added per worker in Korea relative to the G7 is crucial to understanding Korea's overall growth.

Our coverage is from 1962/1963 through 1995, the period that constitutes the growth miracle and that precedes the Asia financial crisis.[20] We assume that Korea was in a steady-state in 1962/1963 in which the current tariff rates are expected to remain forever. Then there is an unexpected tariff reform, e.g., the reduction in Korean tariffs to their 1989 value – and this new policy is expected to remain in place forever. We compute the new steady-state and compare that to data from 1995.[21] Our primary growth assumption is that the growth rate of the parameters that govern the mean productivities, T_{ix}, is constant across the two countries. That is, the two countries have identical long run per capita growth rates. As the goal of our paper is to focus on Korea's catch-up in value-added per worker to the G7, with no loss of generality, we set the long run growth rate of $T_{ix} = 0$. Similarly, we set the growth rate of the labor endowment to be zero, as

[18] Uy, Yi, and Zhang (2013), among others, study Korea's structural change, but in a framework without capital accumulation and without multi-stage production. Moreover, there are no independent measures of tariffs; all trade costs are backed out from the model.

[19] According to Young (1995), TFP growth in manufacturing between 1966 and 1990 was almost twice as high as in the services sector. (Young does not compute TFP growth for agriculture.) Uy, Yi, and Zhang (2013) compute TFP growth for manufacturing, agriculture, and services in Korea between 1970 and 2005, and find that it was 2.2%, 1.8%, and 1.7%, respectively.

[20] 1962 is a desirable starting date, because it is the first full year after Park took office. However, much of our initial data is available only for 1963.

[21] We compare the steady-state of the model economy with the 1989 tariffs to data from 1995 to allow for the transition dynamics to complete. We leave an analysis of the transition dynamics for future work.

well.[22]

The parameters and variables that are calibrated include the labor endowments L_i of each country; the intermediate input shares θ_1 and θ_2, the capital income share, the Frechét heterogeneity parameter n, the Frechét mean productivity parameters T, the capital depreciation rate δ, the preference discount factor β, the intertemporal elasticity of substitution σ, and the trade cost measures for each country and sector τ. The trade costs include tariff rates b, and all other trade costs tr.

The labor endowment, intermediate input shares, capital income share, and tariff rates are set to match their data counterparts. The Frechét heterogeneity parameter n, capital depreciation rate, preference discount factor, and intertemporal elasticity of substitution draw from past, related research. The Frechét mean productivity parameters for the consumption and investment sectors and "all other" trade costs for consumption goods and investment goods are set so that the model matches Korea's initial relative value-added per worker, export share of value-added, and shares of trade that correspond to investment goods and final consumption goods — all in the manufacturing sector. The challenge for the model is whether simulating the tariff liberalizations will quantitatively replicate the *growth* in relative value-added per worker, in trade, and in other variables that are in the data.

We begin by describing our measures of tariff rates. We then show how the other variables and the parameters of the model are calibrated.

4.1 Tariff Rates

We now construct the data counterpart of the tariff component, $(1 + b_{ij})$, of trade costs between country i and country j, $(1 + \tau_{ij}) = (1 + b_{ij})(1 + tr_{ij})$.[23] We assume that there are no distortions in the economy other than the trade barriers. Westphal and Kim (1977) demonstrate that Korean manufacturing exporters operated in an essentially free-trade environment (once the reforms were

[22] Employment in the manufacturing sector actually grew quite rapidly during this period, as high and rapidly growing wages drew workers who might otherwise have gone to other sectors into manufacturing. See Kim and Topel (1995). However, because we do not model the other sectors, we believe the most appropriate assumption is to hold the labor endowment constant, and focus only on the effects of the tariff reductions *given* the labor endowment. One by-product of this assumption is that implicitly wages will be higher in manufacturing than in other sectors.

[23] In an earlier version, we calculated transport costs by using Korea's cost, insurance, and freight (cif) imports / free on board (fob) imports ratio in 1962. Data from the 1992 IMF IFS yearbook yielded a transport cost of 9.2 percent. However, Hummels and Lugovskyy (2006) show that small amounts of measurement error in the cif and fob numbers can have large effects on the magnitude of these costs.

But our simulations did not involve changes in transport costs; hence, our approach in the previous version is equivalent to our approach in this version, in which we interpret all other trade costs as including transport costs.

implemented).

We obtain measures of Korean tariff rates from Nam (1995). This is for all merchandise.[24] As import-weighted average tariff rates are well known to have downward biases, we use his simple average measure. He reports this average for several years between the early 1960s and the mid 1990s. The average tariff rate was 39.9 percent in 1962 and remained at a high level until the 1970s. Thereafter, it declined steadily to 12.7 percent in 1989. We obtain measures of G7 manufacturing tariff rates from Yi (2003). This is an average of the United States tariff and a tariff measure that is a weighted average of Japanese and European Community tariff rates.[25] These tariffs apply to all stages of all goods, except for the tariff exemption policy we will implement below. The initial and post-reform tariff rates are listed in Table 3 below.

Table 3: Average Tariff Rates (percent)

	Country	
	Korea	G7
1962	39.9	13.95
1989	12.7	5.00

Sources: Nam (1995) and Yi (2003)

4.2 Calibration of Other Variables and Parameters

Korea's manufacturing employment grew substantially over this period, while the G7 employment remained relatively stable. We calibrate the labor endowments L_i to match average manufacturing employment in Korea and the G7.[26] This yields employment of 2.8 million for Korea and 60.5 million for the G7.

Turning to the intermediate shares, θ_1 and θ_2, when $\theta_1 = \theta_2 = \theta$, it can be shown that the value-added/gross output ratio in each country is $1 - \theta$. In Korea, the manufacturing value-added/gross output ratio in 1963 was 0.31. In the G7 nations, this ratio ranged from a low of 0.32 (Japan) to

[24] Agriculture and mining goods appear to constitute a small number of the total number of goods, so that while these tariffs tend to be lower than manufacturing tariffs, we believe this discepancy exerts only a minor influence on our results.

[25] Our G7 measure excludes Canada, and includes countries outside the G7. However, because these additional countries are not large, we believe that this discrepancy will not exert a large effect on our results.

[26] For Korea, the average is over our sample period, 1963 to 1995. For the G7, the average is taken over 1970 to 1995. See Appendix A.2.2 for data sources.

a high of 0.39 (United States).[27] We set $\theta_1 = \theta_2 = \theta = 2/3$.

The labor income share, $1 - \alpha$, varies widely across countries. According to Young (1995), Korea's labor share of value-added in manufacturing was 0.504 percent in the early 1960s. From the STAN database, the manufacturing labor income share in 1970 ranged from a low of 0.399 (Japan) to 0.742 (United Kingdom). In the United States, it was 0.728. We set $1 - \alpha = 0.6$.

Three dynamic parameters are set by using values from related research. Ogaki, Ostry, and Reinhart (1996) estimate the intertemporal elasticity of substitution, $1/\sigma$, to be 0.6 for developing countries. The next two parameters are drawn from Backus, Kehoe, and Kydland (1994). We set the annual capital depreciation rate, δ, to 0.1.[28] Finally, we set β, the preference discount factor, to 0.96, which corresponds to a real interest rate in steady-state of a little more than 4 percent.

The heterogeneity in productivity parameter, n, is the key trade elasticity parameter. Higher values of n imply a greater responsiveness of trade to changes in tariff rates and other trade costs. We assume this parameter is identical across countries. EK's estimates of n range from 3.6 to 12.86; their preferred estimate is 8.28. Other prominent estimates of the elasticity of substitution include Baier and Bergstrand (2001) and Head and Ries (2001), who obtain estimates of 6.43 and 7.9, respectively. Head and Mayer's (2014) preferred estimate is 5.03. Overall, estimates tend to be in the $5 - 10$ range.[29] In the previous section, we demonstrated that under multi-stage production the responsiveness of trade to trade costs depends on both n and the "magnification effect" engendered by the intermediate share θ_2. Hence, simply setting n to 8.28, for example, is not appropriate. Instead, we follow the approach of Edmond, Midrigan, and Xu (2012): we use our model to compute the partial elasticity of trade under different values of n.[30] We define the partial elasticity as the log change in the ratio of imports to domestic spending with respect to a one percentage point change in trade costs holding factor prices, goods price indices, and the capital stock constant. In other words, in the calculation, we do not take into account general equilibrium effects on price indices, factor prices, and capital accumulation. We solve for the value of n that generates a partial elasticity of trade = 9.29, which is the estimate that Caliendo and Parro (2014) obtain for Mexico's manufacturing sector in 1993 using an EK framework.[31] We

[27] There were no data for West Germany in 1970.

[28] Given that most investment goods produced by the manufacturing sector are equipment, a higher depreciation rate might be warranted. We solved the initial steady-state, as well as the effects of all three trade reforms, using the equipment depreciation rate from Jorgenson, Gollop, and Fraumeni (1987), 0.13. The results were virtually identical.

[29] Simonovska and Waugh (2012) show that one approach used in EK yields estimates of n that are upwardly biased. They employ an estimator to correct for the bias. Their estimate for n is about 4.

[30] We thank one of the referees for this suggestion.

[31] Edmond, Midrigan and Xu (2012) choose their relevant elasticities to generate a partial elasticity of trade of 8.

choose this estimate for two reasons. First, it is in the range of the elasticities estimated in the empirical research. Second, Mexico's manufacturing sector in 1993 may be a good approximation to Korea's manufacturing sector a decade or two earlier. We find that our model generates that elasticity when $n = 3.96$. This is the value of n that we use.

The final parameters to specify are the Frechét mean productivity parameters, T_{iC} and T_{iI}, for the two stages of the consumption good and the single investment stage for each country – six parameters total – and all other trade costs for trade between the two countries in each of the two consumption stages and the single investment stage. With no loss of generality, we normalize the productivity parameters for the G7 consumption and investment sectors to 1. We assume that Korea has no particular comparative advantage in stage 2 production relative to stage 1 production. This reduces the six productivity parameters to effectively two. We also assume that there is a single all other trade cost that applies to the final (stage 2) consumption goods imported by Korea, $tr_{RK,C2}$, and there is a single all other trade cost that applies to investment goods, and stage 1 and 2 consumption goods imported by the G7, and to investment goods and stage 1 consumption goods imported by Korea. This reduces the number of distinct all other trade costs to two, and also captures the fact that stage 2 consumption goods faced strict quotas in Korea in the early 1960s. We set the two productivity parameters and the two all other trade costs so that the model matches four key facts about Korea in 1963: Korea / G7 manufacturing value-added per worker; Korean manufacturing export share of manufacturing value-added; the share of imported investment goods in Korea's manufacturing value-added; share of Korea's manufacturing imports that are consumption goods.[32]

Our data counterpart to the model's GDP per worker is manufacturing value-added per worker. This variable needs to be measured in consistent units across counties. We use current exchange rates to convert GDP into common units across countries; hence, our measure of GDP per worker in each country is the current dollar value of manufactured value-added per worker. We justify this for three reasons. First, manufactured goods tend to be highly tradable, so that the law of one price is relatively more likely to apply. Second, our primary data metric is a ratio, i.e., the

[32]Details on the calculation of manufacturing GDP per worker are given in Appendix A.2.1. The other three targets are obtained from the U.N. Comtrade database and the 1963 Korea input-output tables. A key issue in calculating the international trade targets is reconciling the balanced trade assumption of the model with the fact that Korea ran a substantial current account deficit in 1963. We assume that Korea's imports in 1963 equal its actual exports in that year. This is mainly because at that time Korea's deficit was financed primarily via foreign aid from the United States, and that aid was mainly in the form of grants, not loans. In the absence of that foreign aid, it is likely that its imports would have been much lower and closer to its exports. The four data targets are listed in Table 4. Matching these targets also implies that the model will match the share of intermediates in Korean trade.

ratio of Korea's value-added per worker in current dollars to G7 value-added per worker in current dollars. This eliminates effects associated with inflation. Third, using a nominal measure avoids the problems that arise when using real measures indexed to a base year in evaluating changes in policies, as discussed in Kehoe and Ruhl (2008).

We must also ensure that the model concept of relative GDP per worker matches with the data measure. The natural model counterpart to our data measure is GDP per worker measured in terms of a common unit; we choose the common unit as the G7 consumption good. An alternative would be to measure Korea's GDP per worker in terms of its own consumption goods, but it would not be appropriate to compare Korea's GDP in terms of its consumption goods against G7 GDP in terms of *its* consumption goods, because they may have different prices, i.e., the real exchange rate may differ from one. Indeed, our simulations deliver real exchange rates that differ from one; moreover, the real exchange rate changes in response to the changes in trade policies.

Table 4: Other Calibrated Parameters and Variables

Parameter		Value
Korea labor, L_{Korea}		2.839
G7 labor, L_{G7}		60.55
Intermediate input share, $\theta_1 = \theta_2$		2/3
Capital income share, α		0.4
Frechét heterogeneity, n		3.96
Intertemp. elasticity of substit., $1/\sigma$		0.6
Capital depreciation rate, δ		0.1
Preference discount factor, β		0.96
	Targets in 1963	
$\left(\frac{T_{Korea,C}/L_{Korea}}{T_{G7C}/L_{G7}}\right)$	$\frac{Y_{Korea}/L_{Korea}}{Y_{G7}/L_{G7}}$ (0.1712)	0.116
$\left(\frac{T_{Korea,I}/L_{Korea}}{T_{G7,I}/L_{G7}}\right)$	Korean export share of GDP (0.1469)	0.069
$tr_{G7K,C2}$	Consumption share of imports (0.02523)	0.615
$tr_{ij,I}; tr_{ij,C1}; tr_{KG7,C2}$	Imported investment share of GDP (0.03991)	0.206

Table 4 lists all the calibrated parameters and variables. The last four rows of the table show the values of the productivity parameters and trade costs that enable the model to meet the four targets in the initial steady-state. For ease of interpretation, the productivity parameters are normalized relative to the labor force in each country. The productivity parameters indicate that Korea has a comparative advantage at producing consumption goods over investment goods. Also, the all other trade costs for final consumption goods imported by Korea (61.5 percent) are considerably higher than the all other trade costs for other goods imported by Korea and all goods imported by the G7 (20.6 percent). This suggests that Korea's extensive quota and quantitative restriction system applied primarily to final consumption goods had a strong impact, and helps explain the very low share of Korean imports that were consumption goods (2.52 percent). The total trade cost for Korean imports of stage 2 consumption goods, including tariffs and all other trade costs, in 1962 was $1.399 \times 1.615 - 1 = 126.0$ percent.

4.3 Solution

Given the parameterization of the model in Table 4 and the tariff data in Table 3, the model will deliver an equilibrium set of factor prices, goods prices, production quantities, trade flows, and vertical specialization flows. We first solve for the initial steady-state in 1963. Then, we simulate the trade policy reforms, individually and in aggregate. The production structure of our model – with endogenous solutions of which country produces which stage of the consumption goods – implies that, unlike in EK, an exact solution to the model cannot be computed. Instead, we must find an approximate solution. To do so, we approximate the $[0, 1]$ continuum with 2,500,000 equally spaced intervals; each interval corresponds to one good or one stage of one good. Further details on the solution method are in Appendix A.3.

5 Results

We now assess the quantitative importance of the three sets of tariff reductions – holding all other parameters and exogenous variables constant – in explaining Korea's catch-up to the G7 in manufacturing value-added per worker and export share of value-added. We also assess whether the model can replicate the changing sectoral composition of its trade. (As a reminder, GDP in the model corresponds to manufacturing value-added in the data.)

Table 5 presents the initial steady-state along with the corresponding data. The first four columns are calibrated to match the data. Among the two columns on the right, note that the model implies an initial steady-state VS/Y ratio that is about 1/7 of what it is in the data. On the other hand, it implies an initial capital share devoted to domestic sales that is close to the true value of 0.98.[33]

Table 5: Initial Steady-State for Korea

Variable	$\frac{Y_K/L_K}{Y_{G7}/L_{G7}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{VS}{Y}$	$Kshare$
Actual data (1963)	0.171	0.147	0.0399	0.0252	0.0494	0.98
Initial steady-state	0.171	0.147	0.0399	0.0252	0.0072	0.92

Note: Y, GDP; L,labor; X, exports; VS, vertical specialization; Inv_M and Con_M, imported investment and consumption; Kshare, share of capital that is for domestic sales;

Table 6: Main Results

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$
Actual data (1963)	0.171	0.147	0.040	0.025
Actual data (1995)	0.395	0.923	0.42	0.095
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33
Trade policy reform	(log) Growth rate implied by model			
(1) Korea tariff exemption	**0.0969**	0.74	0.69	−0.48
(2) Korea tariff reduction (27.2 pp)	**−0.0336**	1.19	1.10	0.051
(3) GATT tariff reduction (8.95 pp)	**0.0951**	0.40	0.36	0.030
(2)+(3)	**0.0922**	1.50	1.32	0.154
(1) + (2) + (3)	**0.143**	1.81	1.60	−0.075

Note: Y, GDP; L,labor; X, exports; M, imports; Inv_M and Con_M,imported investment and consumption; pp, percentage points;

The first two rows of Table 6 present the actual data in 1963 and 1995, respectively. In the third row, we report the log growth rate of the data between 1963 and 1995.[34] We refer to the growth rate of relative manufactured value-added per worker, 83.7 percent, as Korea's "catch-up"

[33] We compute Korea's VS/Y in the model the way it would be computed from an input-output table that does not distinguish between imported inputs that are used to produced export goods and imported inputs that are used to produce domestic goods, and compare this model measure to its data counterpart. That is, our model measure is not the true measure, but what would be measured based on typically available data.

[34] In EK, the effect of changes in tariffs on trade shares is non-linear; specifically, it is linear in logs. While our model has additional non-linearities, owing to its production structure, we believe presenting results in logs facilitates easier intuition about the results.

to the G7.

Our presentation of the main results will proceed by variable. The first variable, given by the left-most column of numbers, is the growth in GDP per worker in Korea relative to the G7, $\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$. The row labeled "(1)+(2)+(3)" at the bottom of the table gives the model's implication of all three trade policies. They generate an increase in Korea's relative GDP per worker of 12.3 percent.[35] This increase is 17.1 (= 0.143/0.837) percent of Korea's actual catch-up. That a single set of policies can explain 17.1 percent of Korea's catch-up seems significant; however, it obviously leaves more than 80 percent unexplained.

The other rows give the effect on Korea's relative GDP per worker of the trade policies in isolation, as well as the two tariff reductions implemented together. For example, the tariff exemption, shown in the row labeled "(1)", leads to an increase in relative GDP per worker of 9.7 percent.[36] The row labeled "(2)" shows that Korea's tariff reduction leads to a decline in its relative GDP per worker of 3.4 percent. This result is driven by the fact that Korea's terms of trade deteriorates with the lower tariffs. Related, Korea's real exchange rate depreciates by more than 10 percent, which implies that Korea's consumption good is valued less in terms of the G7 consumption good. Finally, note that the effect of all three policies implemented together ("(1)+(2)+(3)") is less than the sum of the effects of Korea's tariff exemption "(1)" and the two tariff reductions implemented together "(2)+(3)". This is because the effect of the Korean tariff exemption is larger the higher the initial Korean tariff rate. When Korea's tariff rate is also reduced, the effect of the exemption is diminished. In the extreme, if Korean tariffs are reduced to zero, the marginal effect of the exemption would be zero. Hence, the two Korean trade policies are, in this sense, substitutes.

The second variable is the growth in Korea's export share, $\frac{X}{Y}$. The row labeled "(1)+(2)+(3)" shows that all three policies implemented together yields an increase in the export share, 181 percent, that is very close to the actual increase of 184 percent. The Korea tariff reduction generates a larger increase in exports, 119 percent, than the Korea tariff exemption, which generates an

[35] Both countries' GDP per worker rises, but owing to its smaller size, Korea's grows by about two orders of magnitude more.

[36] In the early years of Korea's trade reforms, government officials found it difficult to enforce the tariff exemption policy. Taken literally, the policy implied that duty-free imported inputs and capital could not be used at all for production for domestic sale. In practice, owing to wastage allowances, cheating, and other forces, these inputs and capital were often used for domestic production and sale. Indeed, this led to a shift in policies over time from an outright exemption to a duty drawback type of policy in which exporters had to first pay the full price for imports and then file paperwork to claim the rebate. (See Ianchovichina (2007) for an analysis of duty drawbacks.) In an earlier version of this paper, we modeled the "leakage" of these imported inputs and capital, by modifying the tariff exemption policy to allow for duty-free importation of inputs and capital goods for domestic sale, as well. A simulation of all three policies yielded, not surprisingly, greater explanatory power for Korea's catch up in relative GDP per worker.

increase of 74 percent. Both policies generate a larger increase in exports than the GATT tariff reduction, although the increase in export share per percentage point reduction in tariffs is about the same across the two types of tariffs.

The final two variables give the growth in the imported investment goods share of GDP and the (final) consumption goods share of imports. The model does fairly well in capture the growth in imported investment goods, but it generates counterfactual implication for the consumption share of imports. The Korea and GATT tariff reductions together imply an increase in the consumption share, but it is far short of the actual increase of 133 percent. In addition, the tariff exemption encourages imports of inputs and capital goods, thus "crowding out" imports of consumption goods; this policy dominates the other two, and the overall effect of all three policies is to reduce the consumption share of imports. We return to this subject in the next section.

Summarizing the final row of Table 6, the model implies that all three trade policies can explain about 17 percent of Korea's catch-up, virtually all of Korea's trade growth, the majority of Korea's increase in imports of investment goods, but none of the increase in imports of consumption goods.

Table 7: Welfare

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{C}{L}$
Actual data (1963)	0.171	
Actual data (1995)	0.395	
Actual growth rate (1963-95, logs)	**0.837**	
Trade policy reform	(log) Growth rate implied by model	
(1) Korea tariff exemption	**0.0969**	0.052
(2) Korea tariff reduction (27.2 pp)	**−0.0336**	0.082
(2a) Korea Cons tariff reduction	**−0.051**	0.051
(2b) Korea Inv tariff reduction	**−0.0037**	0.030
(3) GATT tariff reduction (8.95 pp)	**0.0951**	0.064
(2)+(3)	**0.0922**	0.176
(1) + (2) + (3)	**0.143**	0.191

Note: Y, GDP; L,labor; C, consumption; VS, vertical specialization;

Table 7 presents the model's implications for welfare. The change in welfare is captured by the change in consumption per worker. The first column of numbers presents for comparison the results for the growth in Korea's relative GDP per worker. The second column presents the results for growth in consumption per worker. The column shows that all of the trade policies achieve welfare gains. In other words, Korea's initial tariffs-cum-trade costs are clearly above optimal. In the rows labeled "(2a)" and "(2b)", we separate the Korea tariff reduction into two parts, one applied only to consumption goods and one applied only to investment goods. Each tariff reduction also results in welfare gains.

The difference between the (relative) GDP gains and the consumption gains is primarily the change in Korea's real exchange rate. For example, the GATT tariff reduction leads to an appreciation of Korea's real exchange rate (via an improved terms of trade). Measured in terms of the G7 aggregate consumption good, Korea's GDP has increased, but part of that is simply because the cost or price of Korea's aggregate consumption good has risen relative to that of the G7. Hence, Korea's higher GDP does not translate one-for-one into higher Korean consumption. By contrast, Korea's tariff reductions lead to consumption gains that are greater than the change to GDP. This is because Korea's aggregate consumption price falls (i.e., its real exchange rate depreciates). Here, even though GDP declines, consumption increases. The tariff exemption is an interesting case. On the one hand, it leads to a terms of trade deterioration; and the relative price of exempted investment goods falls, as well. On the other hand, the ultimate beneficiary of the tariff exemption is the G7 consumer; the price of the G7 aggregate consumption good falls relative to Korea's. Korea's real exchange rate appreciates. This generates welfare gains that are smaller than the GDP gains.

Finally, if we compare the welfare results with the export results in Table 6, we can see that there is not a perfect correlation between increases in welfare and increases in trade. In particular, the tariff exemption leads to a much smaller consumption gain per unit increase in trade than does the GATT tariff reduction.

To understand further the quantitative importance of two key transmission channels, we engage in three further simulations. We first assess the importance of imported investment goods. To do this, we study the effects of the three trade policy reforms when trade in investment goods is not allowed, and compare it to a baseline when such trade is allowed. The row labeled "(1)+(2)+(3) without imported investment"of Table 8 presents the results of that simulation.[37] For comparison,

[37] To compute the gain in Korea's relative GDP per worker when investment goods are not traded, we first compute the initial steady-state in 1963 with no trade in such goods. We do not change any other parameters. We then implement all three trade reforms and compute the new steady-state. We do similar pairs of simulations for the exercises in the final two rows of Table 7.

the preceding row presents the results of the three policies in the benchmark model. When trade in investment goods is not allowed, the increase in Korea's relative GDP per worker is about 3/5 as large compared to the benchmark model. Put differently, access to trade in investment goods generates more than a 60 percent larger catch-up. The right-most column shows that welfare gains are about 1/3 larger.

Table 8: Role of Imported Investment and Multi-Stage Production

Variable	$\frac{Y_{Kt}/L_{Kt}}{Y_{G7t}/L_{G7t}}$	$\frac{X}{Y}$	$\frac{\text{Inv}_M}{Y}$	$\frac{\text{Con}_M}{M}$	$\frac{C}{L}$
Actual data (1963)	0.171	0.147	0.040	0.025	
Actual data (1995)	0.395	0.923	0.42	0.095	
Actual growth rate (1963-95, logs)	**0.837**	1.84	2.36	1.33	
Trade policy reform	(log) Growth rate implied by model				
(1) + (2) + (3)	**0.143**	1.81	1.60	−0.075	0.191
(1)+(2)+(3) without imported investment	0.089	1.77	0.00	−0.081	0.145
(2)+(3)	**0.0922**	1.50	1.32	0.154	0.176
(2) + (3) without multi-stage production	0.0390	1.50	1.21	0.728	0.091
(2)+(3) without multi-stage production and without imported investment	−0.0388	1.88			0.042

Note: Y, GDP; L,labor; X, exports; M, imports; Inv_M and Con_M,imported investment and consumption; C,consumption

Second, we assess the importance of multi-stage production. We start from an initial steady-state with no multi-stage production. We then implement the broad Korea tariff reduction and the GATT tariff reduction and compare the effects against the effects of these two policies in the benchmark model.[38] The results are given in the rows labeled "(2)+(3)" and "(2)+(3) without multi-stage production". They show that multi-stage production facilitates a more than twice as large increase (0.0922 vs. 0.0390) in Korea's relative GDP per worker.

Third, we assess the importance of imported investment goods and multi-stage production, together. We implement the broad Korea tariff reduction and the GATT tariff reduction starting

[38] We do not include the tariff exemption policy, because our characterization of it requires multi-stage production. It is possible to modify the model to implement the tariff exemption without multi-stage production — by making exports a separate activity from domestic production and by having imported inputs and capital a part of the export production process — but this would be a significant change from our benchmark model.

from an initial steady-state without imported investment goods and without multi-stage production. The results are given in the final row of Table 8. The table shows that Korea's GDP per worker relative to the G7 declines by 4 percent. Also, welfare is 75 percent lower without these two channels. The two transmission channels, then, explain all of the GDP effects and most of the welfare effects of the Korea and GATT tariff reductions. This is one of the main results of the paper.[39]

6 Further Results

This section provides several further results that help establish that the model can explain other key features of the data well. Table 9 presents the model's implications for vertical specialization. The row labeled "(1)+(2)+(3)" shows that when all three tariff policies are implemented together, the model implies vertical specialization as a share of GDP (0.215) that is fairly close to the actual data value (0.289).[40] Table 9 shows that each policy individually leads to an increase in vertical specialization — that is, lower tariffs encourage greater specialization, including breaking up production chains so that one stage is produced in one country and the second stage produced in another country and some of it exported back to the first country. Also, we do a simulation in which Korea's tariff reduction occurs from a baseline of the tariff exemption already in place. We find that the domestic content of Korea's exports increases. This is consistent with empirical findings from Brandt and Morrow (2014) on China, who find that lower Chinese tariffs lead to an increase in "ordinary" exports, or those exports that do not involve processing of imported inputs.

We do a growth accounting exercise with the model's implied capital stock and GDP resulting from implementing all three tariff reductions. We convert Korea's GDP and capital into consump-

[39] We do one additional exercise to assess the importance of capital accumulation, trade in investment goods, and multi-stage production, taken together. We calibrate a standard EK model with one sector and with labor as the only factor of production, and in which $n = 9.29$. We calibrate the relative TFPs and the all other trade cost so that the model matches the initial relative manufactured value-added per worker, and Korea's initial trade share. We then investigate the effects of reductions in Korea's tariffs and/or the GATT tariffs. (For simplicity, we model tariffs as iceberg costs, i.e., the revenue is not rebated; this should enhance the GDP effects of lower tariffs.) We find that this model implies increases in Korea's trade that is similar to that in the benchmark model, but the implications for GDP and welfare are considerably smaller than in the benchmark model. For example, in response to the two tariff reductions, this model implies an increase in trade of 132 percent, but a decline in Korea's relative GDP of 2.5 percent, as opposed to an increase in trade of 150 percent and an increase in relative GDP of 9.2 percent in the benchmark model. These results again point to the importance of the "additional features" of the model beyond standard trade models.

[40] Koopman, Wang, and Wei (2012) show that in the presence of policies that explicitly encourage vertical specialization, the HIY methodology for computing VS underestimates the true level of VS. This suggests that the actual VS in Korea in 1995 was greater than the reported number.

VS in the G7 increases, as well. In long terms the increase is large, but it starts from a very low base.This is consistent with evidence from HIY, and also from Johnson and Noguera (2014).

tion units, as we did with the actual data. We find that 86% of the growth in GDP per worker is attributable to TFP with the remainder to capital accumulation. This is virtually the same as the 87% share in the data reported in Table 1, and indicates that the model matches this feature of Korea's growth experience very well. Moreover, the result that tariff reductions, including input tariff reductions, lead to productivity gains is consistent with the empirical research by Pavcnik (2002), Amiti and Konings (2007), and Halpern *etal* (2011).

Table 9: Vertical Specialization

$\frac{VS}{Y}$	1963	1995
Actual data	0.0494	0.289
Model		
Initial steady-state	0.0075	
(1) Korea tariff exemption		0.0351
(2) Korea tariff reduction (27.2 pp)		0.0654
(2a) Korea Cons tariff reduction		0.0628
(2b) Korea Inv tariff reduction		0.0075
(3) GATT tariff reduction (8.95 pp)		0.0169
(2)+(3)		0.129
(1) + (2) + (3)		0.251

Note: Y, GDP; VS, vertical specialization; pp, percentage point

Finally, we briefly discuss the model's counterfactual implications for the consumption share of imports.[41] In our simulations we hold constant "all other trade" costs of importing final consumption goods. As mentioned above, at least some of these "all other trade" costs are captured by quotas and quantitative restrictions. Over time, the quotas were relaxed. For example, Korea went from a positive list quota system, in which goods not subject to quotas were explicitly listed, to a negative list system, in which goods subject to quotas were explicitly listed, in 1967. Under the new policy, then, the presumption was that goods would not be subject to quotas unless otherwise specified. Hence, this policy likely led to a greater share of consumption goods in imports than

[41] This counterfactual implication bears some similarity to the counterfactual result on consumption and investment co-movement from a closed economy real business cycle model in response to an investment shock. See Raffo (2009).

otherwise.[42] Unfortunately, the lack of quantitative data on the changes in these quotas and quantitative restrictions prevents us from including it as one of our main trade policies. However, we conduct a simulation in which, in addition to the three tariff policies, we also reduce the "all other" trade costs for Korean stage-2 consumption goods by 27.2 percentage points, i.e., the same amount as the Korean tariff decline. In this scenario, the consumption share of imports rises significantly to 14 percent, more than the 9.5 percent in the data.[43]

7 Conclusion

We study the effects of trade policy reforms on the growth of South Korea's manufacturing value-added per worker using a neoclassical model of growth and trade. South Korea's growth miracle in the three-plus decades following 1961 have been well-documented. There were three key trade reforms. Korea granted tariff exemptions on imported inputs and capital goods used to make export goods. Korea also engaged in a broad tariff reduction. Finally, the advanced nations, the recipients of most of Korea's exports, lowered their tariffs through two GATT rounds, the Kennedy and Tokyo rounds.

We calibrate our model to South Korea and the G7 countries. Our simulations show that the tariff exemption policy and the GATT tariff reductions increased Korea's relative per worker GDP, while Korea's own tariff reductions decreased its relative per worker GDP. The three policies taken together explain about 17 percent of Korea's catch-up to the G7 in manufacturing value-added per worker. Our model can match Korea's increase in trade. It also implies substantial increases in vertical specialization and in imported capital goods – close to the actual increases. However, the model delivers counterfactual predictions for the importance of consumption goods in trade. Our simulations also show that each of the three trade policies leads to welfare gains, and all three policies together lead to an increase in consumption of 19 percent. Further analysis shows that access to imported investment goods, as well as multiple stages of production and the additional specialization this engenders, are the dominant channels in generating the above findings.

How do we interpret our results in light of Rodrik and Rodriguez (2000), as well as other research

[42] Anderson and Neary (1992) show that in the presence of both tariffs and quotas, a reduction in tariffs reduces the effect of quotas. Intuitively, it is because lower tariffs lead to substitution from the goods subject to quotas to goods subject to the tariffs. We thank Jim Anderson for this insight. In our framework, the quotas are captured implicitly by an iceberg trade cost that remains constant as tariffs are reduced.

[43] The increase in the consumption share comes at the expense of imports of intermediate goods. By contrast, the capital goods import share increases by almost as much as in the benchmark simulation of the three tariff policies.

by Rodrik that finds that the importance of trade policy is limited?[44] We give two answers. On the one hand, our results are consistent with that research, because we find that the majority of Korea's catch-up cannot be explained by trade policy. On the other hand, our focus on only neoclassical trade and growth transmission mechanisms necessarily means we have ignored other channels by which trade can affect growth. For example, to the extent that learning or technological spillovers are enhanced through exporting and importing, our framework understates the role of trade.[45] Also, to the extent that the prospect of future tariff reductions imply enhanced earnings opportunities, the trade policies would have implications for human capital accumulation.[46] Our findings, then, represent a lower bound on the importance of trade policies in Korea's growth miracle.

Extending our growth framework to allow for endogenous technological change at the level of individual goods, and thus capture some of the mechanisms emphasized in the endogenous and semi-endogenous open economy growth models descended from Grossman and Helpman (1991), is a worthwhile goal. Also, while our paper has focused on Korea's trade policies, Korea implemented many other policies focused on physical and human capital, on output, and on trade. For example, government investment in schools, roads, and other infrastructure increased substantially. Credit subsidies and reduced direct and indirect tax rates were provided to exporters. Finally, Korea has had episodes of targeted industrial policy designed to build up particular industries, such as shipbuilding. More recently, labor markets were reformed and unionization has become prevalent. Studying the effects of these policies in conjunction with the trade policies would be interesting for future research.

A Appendix

A.1 Solution for import share of GDP in the special case of the multi-stage production model

For goods ultimately consumed in the home country, there are two production methods, HH and HF. Following Dornbusch, Fischer, and Samuelson (1977) we can arrange the stage 2 goods in descending order of the ratio of home to foreign productivity of stage 2 production. There is a cutoff $\underline{z}_h$for which goods on the interval $[0, \underline{z}_h]$ are produced by HH, and goods on the interval $[\underline{z}_h, 1]$ are produced by HF. This cutoff is determined by the arbitrage condition that the price of

[44] See, for example, Rodrik, Subramanian, and Trebbi (2004).
[45] See Grossman and Helpman (1991), or more recently, Perla, Tonetti, and Waugh (2014).
[46] See Broda, Greenfield, and Weinstein (2006), and Bils and Klenow (2000).

purchasing this good (by a home country consumer) is the same across the two methods:

$$p_{HH}(\underline{z}_h) \equiv (1+\tau_H)p_{HF}(\underline{z}_h) \Longrightarrow \tag{26}$$

$$\frac{\psi(w_H^{1-\alpha}r_H^{\alpha})^{1-\theta_1\theta_2}(P_H)^{\theta_1\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{H2}(\underline{z}_h)^{1-\theta_2}} = (1+\tau_H)\frac{\psi(1+\tau_F)^{\theta_2}(w_H^{1-\alpha}r_H^{\alpha})^{(1-\theta_1)\theta_2}(P_H)^{\theta_1\theta_2}(w_F^{1-\alpha}r_F^{\alpha})^{1-\theta_2}}{A_{H1}(\underline{z}_h)^{(1-\theta_1)\theta_2}A_{F2}(\underline{z}_h)^{1-\theta_2}} \tag{27}$$

where ψ is a constant. Assuming $\tau_H = \tau_F$, and simplifying yields:

$$\left(\omega^{1-\alpha}\rho^{\alpha}\right)^{1-\theta_2} = \left(\frac{A_2^h(\underline{z}_h)}{A_2^f(\underline{z}_h)}\right)^{1-\theta_2}(1+\tau)^{(1+\theta_2)} \tag{28}$$

which leads to:

$$\omega^{1-\alpha}\rho^{\alpha} = 1 = \left(\frac{1-\underline{z}_h}{\underline{z}_h}\right)^{\frac{1}{n}}(1+\tau)^{\frac{1+\theta_2}{1-\theta_2}} \tag{29}$$

The solution for $\underline{z}_h$ is given by:

$$\underline{z}_h = \frac{(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{30}$$

Home country imports expressed as a share of GDP are given by:

$$\varphi(1-\underline{z}_h) = \frac{\varphi}{1+(1+\tau)^{n\left(\frac{1+\theta_2}{1-\theta_2}\right)}} \tag{31}$$

where φ is a constant that depends on θ_1 and θ_2.

A.2 Data Sources and Construction of Variables

A.2.1 Table 1

Data on manufacturing value-added and gross capital formation (in 2005 won) are from several issues of the Bank of Korea (BOK) Economic Statistics Yearbook. The gross capital formation data is used to construct capital stocks using the perpetual inventory method and assuming a depreciation rate of 10%. The initial capital stock is constructed following Young (1995), footnote 16. The employment data is from the Groningen Growth and Development Centre (GGDC) 10-Sector Database. Total factor productivity (TFP) is constructed using the above data on value-added, capital, and employment with a Cobb-Douglas production function and a capital share of 0.4.

Manufacturing value-added per worker in Korea relative to the G7 in 1963 and 1995 is constructed using a slightly different approach. In particular, we use a "nominal/nominal" approach, rather than a "real/real" approach. This is discussed in the paper in section 4.2. Our sources are the 1972 BOK Economic Statistics Yearbook (ESY), UNCTAD Handbook of International Trade and Development Statistics, the IMF International Financial Statistics (IFS), the Penn World Tables (PWT, 6.1) and the OECD STAN Database. 1963: From BOK ESY, manufacturing value-added was 13.61 percent of total GDP (measured at factor cost). For the G7, we obtain manufacturing value-added as a share of total GDP for 1970 for each country from the OECD STAN database. GDP is measured at basic prices, which are intended to capture the prices that producers receive. We assume that for each country the share in 1963 is the same as in 1970. The UNCTAD handbook reports GDP in 1963 in current U.S. dollars for each country. We multiply the dollar value of

GDP in 1963 by the manufactured value-added shares to obtain total manufacturing value-added for Korea and the G7 in 1963 in current U.S. dollars. For employment, a key goal is to make employment comparable across countries. Our procedure takes into account the fact that Korea was not a member of the OECD at that time; also the OECD STAN database does not have data prior to 1970. We first obtain Korea's manufacturing employment share of total employment in 1963 from the 1972 BOK ESY: 0.0794. To construct the G7 manufacturing employment share in 1963, we assume that in each country, the employment share in 1970 is the same as in 1963. Adding up across countries gives us the overall G7 manufacturing employment share for 1963: 0.263. We then multiply these shares by the Penn World Tables (PWT) workers variable in 1963 to get manufacturing employment in each country: 0.743 million in Korea and 62.1 million in the G7. 1995: The manufacturing GDP data are obtained in local currency units from OECD STAN for Korea and each country in the G7, and are converted from local currency to U.S. dollars by multiplying by the 1995 average exchange rate obtained from the IMF IFS. For employment, we use the OECD STAN for both the G7 and Korea.

The manufacturing GDP data are divided by the employment data to obtain GDP per worker in current U.S. dollars for Korea and the G7 in 1963 and 1995. For 1963, the ratio of Korea to G7 manufacturing GDP per worker was 0.171. In 1995, the ratio was 0.395.

A.2.2 Table 2

The Korea manufactured export share of value-added data come from Korea's 1963 and 1995 input-output tables. Manufacturing includes all industries "between" food, beverages, and tobacco and miscellaneous manufacturing in the tables. GDP is measured at current factor cost.

Korea's imported equipment and machinery is obtained from UN COMTRADE data (SITC, rev. 1 codes 692, 695, 71, 72, and 861) for 1963 and 1995. Manufactured value-added is from Korea's input-output tables.

Korea's vertical specialization is computed using the "VS" measure from Hummels, Ishii, and Yi (2001). The sources are Korea's 1963 and 1995 input-output tables.

A.2.3 Calibration

Most of the sources and data construction are discussed in the text.

Labor endowment: For the G7 countries, we use the OECD STAN database. We use the average between 1970 and 1995. For Korea, our source is the GGDC 10-sector database, and the average is between 1963 and 1995.

Four calibration targets in 1963: Manufacturing value-added per worker in Korea relative to the G7 is discussed above, as is the Korean export share of value-added. The imported equipment share of value-added is adjusted relative to the number presented in Table 2. In particular, as part of the calibration, we set Korea's imports in 1963 equal to its exports for that year. See footnote 32 for our rationale. This requires "shrinking" Korea's imports, including its imports of equipment, by a factor of about six. Imported manufactured consumption goods as a share of total manufactured imports is computed from Korea's 1963 input-output tables. Consumption includes both private and government consumption, as well as increase in stocks for consumption good categories.

A.3 Solution Method

We compute an approximate solution to the model. We approximate the $[0, 1]$ continuum with 2,500,000 equally spaced intervals; each interval corresponds to one good or one stage of one good. We first solve for the initial steady-state, which includes the productivity parameters and trade costs that enable the model to match the four targets: relative per worker output, export share of GDP, investment import share of GDP, and consumption share of imports.

We then solve the model under different combinations of the trade reforms. We reduce the model to ten equations in ten unknowns (two wages, four aggregate price indices, three capital stocks and one aggregate intermediate). For each country, we draw a stage 1 productivity and a stage 2 productivity from the Frechét distribution for each of the 2,500,000 consumption goods and a productivity from the Frechét distribution for each of the 2,500,000 investment goods. We then calculate for each country the cheapest production method for each consumption good and each investment good. Finally, we assess whether the resulting pattern of production, trade, and prices is consistent with labor market equilibrium, capital market equilibrium, intermediates goods market equilibrium, and with the candidate aggregate prices. The model uses a Gauss-Newton algorithm to adjust the candidate vector until these conditions are met. The algorithm takes about 15 minutes in Gauss.

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